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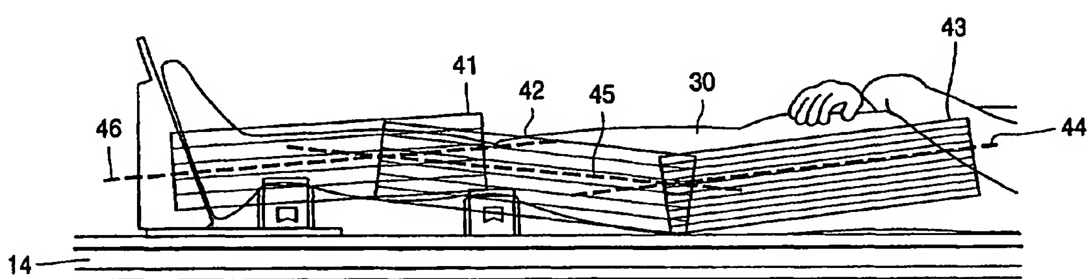
(54) Title: MAGNETIC RESONANCE IMAGING OF SEVERAL VOLUMES.



(57) Abstract: A magnetic resonance imaging method involves the acquisition of sets of magnetic resonance signals from several scan-volumes of an object. According to the invention different spatial approaches are taken in the scanning of the respective scan-volumes. In particular respective scan-volumes include different numbers of scan-slices or scan slices of respective scan-volumes have a different slice thickness or scan-slices of respective scan-volumes have different fields-of-view or scan-slices of respective scan-volumes have different numbers of scanned points in k-space.

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Magnetic resonance imaging of several volumes

The invention relates to a magnetic resonance imaging method comprising the acquisition of sets of magnetic resonance signals from several scan-volumes of an object.

Such a magnetic resonance imaging method and a corresponding magnetic resonance imaging system are known from the US patent **US 5 928 148.**

The known magnetic resonance imaging method pertains in particular to MR-angiography which forms magnetic resonance images of a patient's vascular system. In order to improve contrast of notably the patient's arteries, a contrast agent is administered. According to the known magnetic resonance imaging method magnetic resonance signals are acquired from a large region of interest by translating the patient to successive stations at which the respective sets of magnetic resonance signals are acquired. To this end, the receiver system of the known magnetic resonance imaging system comprises a stationary local receiver coil which is supported adjacent the patient so as to acquire the magnetic resonance signals. In an other embodiment of the known magnetic resonance imaging system the receiver system comprises a multi-segment local coil which is moveable with the patient and its coil segments are sequentially switched into operation. At the successive stations, respective parts of the patient to be examined are moved into the *field-of-view* of the magnetic resonance imaging system. The respective scan-volumes are defined by the respective parts of the patient wherefrom the respective coil segments acquire magnetic resonance signals at the successive stations. It is to be noted that the cited US patent shows a patient's leg which is surrounded by several sets of surface coils. The separate sets of surface coils include different geometrical volumes, however, this does not lead to different scan-volumes for the respective sets of surface coils. The scan-volume is determined notably by the smallest distance in k-space between scanned points in k-space, i.e. the smallest wave vector difference in the magnetic resonance signals. The scan-volume is thus determined by the magnitude of the temporary read gradients and phase-encoding gradients. According to the known magnetic resonance imaging method, the respective scan-volumes must be aligned

so that the sets of magnetic resonance signals can be concatenated in order to form a single MR-image of the entire region of interest.

An object of the invention is to provide a magnetic resonance imaging method which involves the acquisition of several sets of magnetic resonance signals and provides magnetic resonance images having a better diagnostic quality.

This object is achieved by the magnetic resonance imaging method according to the invention wherein different spatial approaches are taken in the scanning of the respective scan-volumes.

As different spatial strategies are employed for scanning the various parts of the object, differences between the shapes of the respective parts of the object are more accurately taken into account. For example, in MR angiography of the lower extremities (the patient's legs), the invention takes into account the different shapes of notably the blood vessel structures of the patient's abdomen, upper and lower legs. The respective scan volumes are accurately matched to the parts of the patient to be examined. Consequently, the magnetic resonance images which are reconstructed from the magnetic resonance signals have a better diagnostic quality in that small details of little contrast are nevertheless rendered well visible. Notably the scan-volumes are adjusted in that the imaging volume and/or the resolution of the magnetic resonance imaging system are adjusted for the individual scan-volumes. This is achieved by setting the smallest separation of points scanned in k-space and the number of points scanned in k-space by suitable control of the temporary read gradients and/or phase encoding gradients and the sampling intervals employed in the acquisition of the magnetic resonance signals, that is, the region in k-space which is scanned and the density of sample points are adjusted for separate scan-volumes.

These and other aspects of the invention will be further elaborated with respect to the preferred embodiments as defined in the dependent Claims.

Spatial approaches in the scanning of the scan-volumes may be realized in various ways. Preferably, the spatial scanning may involve scanning of a number of slices in the respective scan-volumes. According to the invention, the number of slices employed in the individual scan-volumes is adjusted to the relevant part of the patient to be examined. As the parts of the patient to be examined are larger, larger scan-volumes with more slices are

employed. Consequently, good coverage of the entire region of interest is achieved and superfluous scanning of empty, uninteresting or irrelevant space is avoided. Notably the time required for the acquisition of magnetic resonance signals from relatively small scan-volumes is reduced. As the time required for signal acquisition is shorter, the signal acquisition may be completed before the injected contrast agent reaches the patient's venous system. Magnetic resonance signals from the patient's veins are thus avoided so that venous enhancement is avoided in the magnetic resonance image reconstructed from the magnetic resonance signals. Thus, the representation of the patient's arteries in the magnetic resonance image is not obscured by magnetic resonance signals from veins that have become filled with contrast agent.

Alternatively, the slice thickness may be changed. The spatial resolution is thus adjusted in the direction transversely of the slices; this direction is usually indicated as the 'slice direction'. Furthermore, within the slices for respective scan-volumes the *field-of-view* and the *scan matrix*, i.e. the number of samples and the sample density in k-space may be varied. The size of the scan-volume and the resolution parallel to the slices are thus adjusted for the individual scan-volumes. The *field-of-view* is the region in the slice at issue wherefrom magnetic resonance signals are acquired and is determined by the temporary magnetic read gradients and phase-encoding gradients. The *scan matrix* is a two-dimensional matrix whose entries represent the sample points (in k-space) that are determined by the read gradients and phase-encoding gradients. That the spatial resolution in the direction parallel to the slices is varied in this manner.

Hence, according to the invention, the size of the scan-volume and the resolution in all directions can be adjusted for the individual scan-volumes.

Furthermore, contrast parameters that influence the contrast and/or signal-to-noise ratio in the reconstructed magnetic resonance image may be adjusted for separate scan-volumes. These contrast parameters notably include the repetition rate, the echo-time , the flip angle and the bandwidth employed in the pulse sequences of RF-excitations and temporary gradients used for scanning the scan-volumes for magnetic resonance signals.

In another preferred implementation of the invention, the relative orientations of the scan-volumes are adjustable. Adjusting the relative orientations of the respective scan-volumes achieves accurate matching of the scan-volumes to the anatomy of the patient to be examined. The individual scan-volumes are oriented in the same way as the local orientation of the part of the patient to be examined that is scanned in the relevant scan-volume. Individual scan-volumes have a longitudinal axis, for example the direction of the major

dimension of the scan-volume at issue. The orientations of the scan-volumes are, for example, obtained by adjusting the directions of the respective longitudinal axes of the respective scan-volumes to the parts of the patient to be examined. Thus, it is achieved that the scan-volumes adequately follow the shape of the parts of interest of the patient. Notably in the case of MR-angiography of the lower extremities this preferred implementation takes into account the fact that the patient's abdominal region and legs and in particular the blood vessel structure in those regions, are not straight.

Preferably, the magnetic resonance signals are generated and acquired in the respective scan-volumes by respective ways of scanning k-space. The term k-space indicates the reciprocal space of the scan-volumes and positions in k-space represent the wave vectors of the magnetic resonance signals. The scanning of k-space is adapted for the respective scan-volumes. For example, some scan-volumes are scanned from the centre of k-space towards the periphery of k-space, whereas other scan-volumes are scanned while moving inwards in k-space. When the scan-volume relates to a more extreme part of the patient's anatomy, e.g. the lower legs, scanning k-space from the centre outward particularly effectively suppresses magnetic resonance signals from the patient's veins. Preferably, for the first scan-volume, i.e. the scan-volume in which the injected contrast agent arrives first, the magnetic resonance signals are acquired by scanning continuously through the centre of k-space. In this respect continuous scanning implies that the change of the co-ordinates in k-space (i.e. the values of the vector components in k-space) between points in k-space that are scanned one immediately after the other is equal to the smallest co-ordinate change between scanned points in k-space. For instance, after a full read-out of samples in the k_x-direction, the next value of either k_y or k_z is taken with a smallest sampling step from the earlier position in k-space. Particularly good results are obtained by scanning through the centre of k-space linearly, i.e. when the values of the one or several of the vector-components of the k-vector change linearly with time in a neighbourhood of the centre of k-space. As the contrast increases gradually during the k-space scanning of the individual scan-volumes, continuous scanning ensures that differences between contrast values at neighbouring scanned positions in k-space remain small. This avoids artefacts in the magnetic resonance image that are due to large contrast differences at closely situated positions in k-space. Moreover, the linear scanning appears rather insensitive to accurate timing of the start of the scan relative to the arrival of contrast agent. Hence, the peripheral portions of k-space can be easily scanned, without serious artefacts being generated, while contrast agent has arrived in the scan-volume. Hence, a high spatial resolution of the magnetic resonance image is achieved. The

first scan-volume usually relates to the abdominal region of the patient to be examined. In practice it appears that a high spatial resolution of the magnetic resonance image of the abdominal region is relevant in view of diagnostic quality. Furthermore, continuous, in particular linear scanning in k-pace for the first scan-volume involves comparatively fast progress of the scanning of k-space, i.e. faster in comparison with a so-called high-low strategy where the sign of at least one of the components of the k-vector alternates between positive and negative values for points in k-space that are scanned one after the other and the magnitude of the k-vector gradually decreases from the periphery to the centre of k-space. Hence, the scanning of k-space for the first scan-volume needs only a comparatively small amount of time so as to reach the centre of k-space. Thus, magnetic resonance signals at low k-values from the patient's veins are avoided, since the contrast agent has not yet reached the patient's veins when the centre of k-space is scanned quite soon after the injection of contrast agent. This means that the so-called venous enhancement is substantially suppressed by continuous or linear scanning in k-space for the first scan-volume.

The time required for scanning k-space for the first scan-volume may be further reduced by employing partial scanning of k-space in that in the periphery of k-space, i.e. k-vectors with a large magnitude of one of more of its k_x,k_y,k_z components, only positive or only negative values of one or more of these components are scanned. The magnetic resonance signals for parts of k-space which are not actually scanned and are needed for the reconstruction of the magnetic resonance image are obtained, for example by hermitian conjugation from actually acquired magnetic resonance signals. Thus, venous enhancement in the first scan-volume is even further suppressed.

The scanning of k-space for subsequent scan-volumes is preferably performed according to the so-called low-high scanning strategy in which the sign of at least of the components of the k-vector alternates between positive and negative for points in k-space that are scanned one after the other and the magnitude of the k-vector gradually increases from the center to the periphery of k-space. This low-high strategy ensures that portions of k-space having low wave-numbers (k-values) are scanned earlier than portions of k-space having high k-values. Consequently, venous enhancement, i.e. venous signals contributing to the magnetic resonance signals, appears only at high k-values, thus leading to suppression of the venous contribution of the contrast in the magnetic resonance image. These subsequent volumes are scanned after the increase of the contrast, so that the contrast is rather stable during the scanning of these subsequent volumes.

The invention also relates to a magnetic resonance imaging system. The magnetic resonance imaging system according to the invention is defined in the independent Claim 6. The magnetic resonance imaging system of the invention is suitable for carrying out the magnetic resonance imaging method of the invention. This is achieved in practice by suitably programming a computer or micro-processor which controls the magnetic resonance imaging system.

The invention also relates to a computer program as defined in the independent Claim 7. The computer program according to the invention enables the magnetic resonance imaging system to achieve the technical effects involved in performing the magnetic resonance imaging method of the invention. The computer program is loaded into the computer or micro-processor of the magnetic resonance imaging system.

These and other aspects of the invention will be elucidated with reference to the embodiments described hereinafter and with reference to the accompanying drawing wherein

Figure 1 is a schematic representation of the magnetic resonance imaging system in which the invention is employed.

Figure 2 is a schematic representation of the orientation of respective scan volumes according to the invention.

Figure 1 shows diagrammatically a magnetic resonance imaging system in which the invention is used. The magnetic resonance imaging system includes a set of main coils 10 whereby a steady, uniform magnetic field is generated. The main coils are constructed, for example in such a manner that they enclose a tunnel-shaped examination space. The patient to be examined is slid into this tunnel-shaped examination space. The magnetic resonance imaging system also includes a number of gradient coils 11, 12 whereby magnetic fields exhibiting spatial variations, notably in the form of temporary gradients in individual directions, are generated so as to be superposed on the uniform magnetic field. The gradient coils 11, 12 are connected to a controllable power supply unit 21. The gradient coils 11, 12 are energized by application of an electric current by means of the power supply unit 21. The strength, the direction and the duration of the gradients are controlled by control of the power supply unit. The magnetic resonance imaging system also includes transmission and receiving coils 13 for generating RF excitation pulses and for acquiring magnetic resonance signals, respectively. The transmission coil 13 is preferably constructed as a body

coil 13 whereby (a part of) the object to be examined can be enclosed. The body coil is usually arranged in the magnetic resonance imaging system in such a manner that the patient 30 to be examined is enclosed by the body coil 13 when he or she is arranged in the magnetic resonance imaging system. The body coil 13 acts as a transmission antenna for the transmission of the RF excitation pulses and RF refocusing pulses. Preferably, the body coil 13 involves a spatially uniform intensity distribution of the transmitted RF pulses (RFS). The same coil or antenna is usually used alternately as the transmission coil and the receiving coil. Such a coil is usually indicated as a 'synergy coil'. Furthermore, the transmission and receiving coil is usually shaped as a coil, but other geometries where the transmission and receiving coil acts as a transmission and receiving antenna for RF electromagnetic signals are also feasible. The transmission and receiving coil 13 is connected to an electronic transmission and receiving circuit 15.

It is to be noted that it is alternatively possible to use separate receiving coils. For example, surface coils can be used as receiving coils. Such surface coils have a high sensitivity in a comparatively small volume. The transmission coils, such as the body coil and then surface coils, are connected to a demodulator 24 and the received magnetic resonance signals (MS) are demodulated by means of the demodulator 24. The demodulated magnetic resonance signals (DMS) are applied to a reconstruction unit. The receiving coil is connected to a preamplifier 23. The preamplifier 23 amplifies the RF resonance signal (MS) received by the receiving coil 16 and the amplified RF resonance signal is applied to a demodulator 24. The demodulator 24 demodulates the amplified RF resonance signal. The demodulated resonance signal contains the actual information concerning the local spin densities in the part of the object to be imaged. Furthermore, the transmission and receiving circuit 15 is connected to a modulator 22. The modulator 22 and the transmission and receiving circuit 15 activate the transmission coil 13 so as to transmit the RF excitation and refocusing pulses. The reconstruction unit derives one or more image signals from the demodulated magnetic resonance signals (DMS), which image signals represent the image information of the imaged part of the object to be examined. In practice is constructed the reconstruction unit 25 preferably as a digital image processing unit 25 which is programmed so as to derive from the demodulated magnetic resonance signals the image signals which represent the image information of the part of the object to be imaged. The signal on the output of the reconstruction unit is applied to a monitor 26, so that the monitor can display the magnetic resonance image. It is alternatively possible to store the signal from the reconstruction unit 25 in a buffer unit 27 while awaiting further processing.

According to the invention, the patient table 14 with the patient 30 is moved to successive stations and at each station, as indicated by the arrow 40 In practice at the first station the abdominal region of the patient is scanned while at the second station the upper legs of the patient are scanned and at the third station the lower legs of the patient are scanned. At each station the magnetic resonance signals from the scan-volume at issue are acquired and magnetic resonance images are reconstructed.. The scan-volumes are indicated by the reference numerals 41,42 and 43. The patient is shown positioned at the first station 43 in which the first scan-volume of the abdominal region is situated such that the isocenter IC of the magnetic resonance imaging system is located in the first scan-volume 43. Subsequently, the patient table 14 with the patient is moved so that the second scan-volume 42 and the third scan-volume 43 are placed at the isocenter IC. As is indicated schematically in Figure 1, the magnetic gradient fields are adjusted at each station in order that the *field-of-view* matches the local size of the patient at the respective stations.

The magnetic resonance images may be actual two-dimensional images, but also three-dimensional volumes may be reconstructed for the individual scan-volumes. The reconstruction unit 25 is preferably also arranged to combine the reconstructed images or volumes into an overview image or an overview volume which represents the patient's vascular system in the lower extremities. Such an overview shows notably the arterial system with a high diagnostic quality and a high spatial resolution.

The magnetic resonance imaging system according to the invention is also provided with a control unit 20, for example in the form of a computer which includes a (micro)processor. The control unit 20 controls the execution of the RF excitations and the application of the temporary gradient fields. To this end, the computer program according to the invention is loaded, for example, into the control unit 20 and the reconstruction unit 25.

Figure 2 is a schematic representation of the orientation of respective scan volumes according to the invention. In particular, Figure 2 is a side-elevation of the patient 30 to be examined on the patient table 14 in which the respective scan-volumes 43,42 and 41 are indicated. According to the invention the scan-volumes are oriented, for example such that each scan-volume is aligned with the part of the patient at issue in that scan-volume. Consequently, in this embodiment, the longitudinal axes 44,45,46 of the scan-volumes 41,42,43 do not extend in a common direction since the patient's legs are not straight. However, according to the invention, the scan-volumes can optionally be aligned such that their longitudinal axes all extend in a common direction. Such alignment in the common

direction makes it easier to concatenate the magnetic resonance images of the scan-volumes into a single magnetic resonance image.

Furthermore, as is schematically indicated in Figure 2, the number of slices which are scanned for magnetic resonance signals is different for individual scan-volumes. For example, the first scan-volume 43, relating to the abdominal region, contains about 30-33 slices whereas the second scan-volume 42, which relates to the upper legs contains about 20-22 slices and the third scan-volume 41, which relates to the lower legs contains about 19-23 slices. The number of slices employed is selected in these ranges and depends on the relevant patient.

CLAIMS:

1. A magnetic resonance imaging method comprising
   - acquisition of sets of magnetic resonance signals from several scan-volumes of an object, wherein
   - different spatial approaches are taken in the scanning of the respective scan-volumes.

2. A magnetic resonance imaging method as claimed in Claim 1, wherein
   - the individual scan-volumes include several scan-slices and
     - respective scan-volumes include different numbers of scan-slices or
     - scan-slices of respective scan-volumes have a different slice thickness or
     - scan-slices of respective scan-volumes have different *fields-of-view* or
     - scan-slices of respective scan-volumes have different numbers of scanned points in k-space.

3. A magnetic resonance imaging method as claimed in Claim 1, wherein the respective scan-volumes have different orientations.

4. A magnetic resonance imaging method as claimed in Claim 1, wherein the relative orientations of the scan-volumes are adjustable.

5. A magnetic resonance imaging method as claimed in Claim 1, wherein respective ways of scanning k-space are employed for acquiring the magnetic resonance signals from the respective scan-volumes.

6. A magnetic resonance imaging system having
   - a receiver system for receiving sets of magnetic resonance signals from several scan-volumes of an object, and
   - a scanning system for scanning the scan-volumes, wherein

– the scanning system is arranged to apply different spatial approaches to scanning the respective scan-volumes.

7. A computer program comprising instructions for

– receiving sets of magnetic resonance signals from several scan-volumes of an object and
– applying different spatial approaches to scanning the respective scan-volumes.

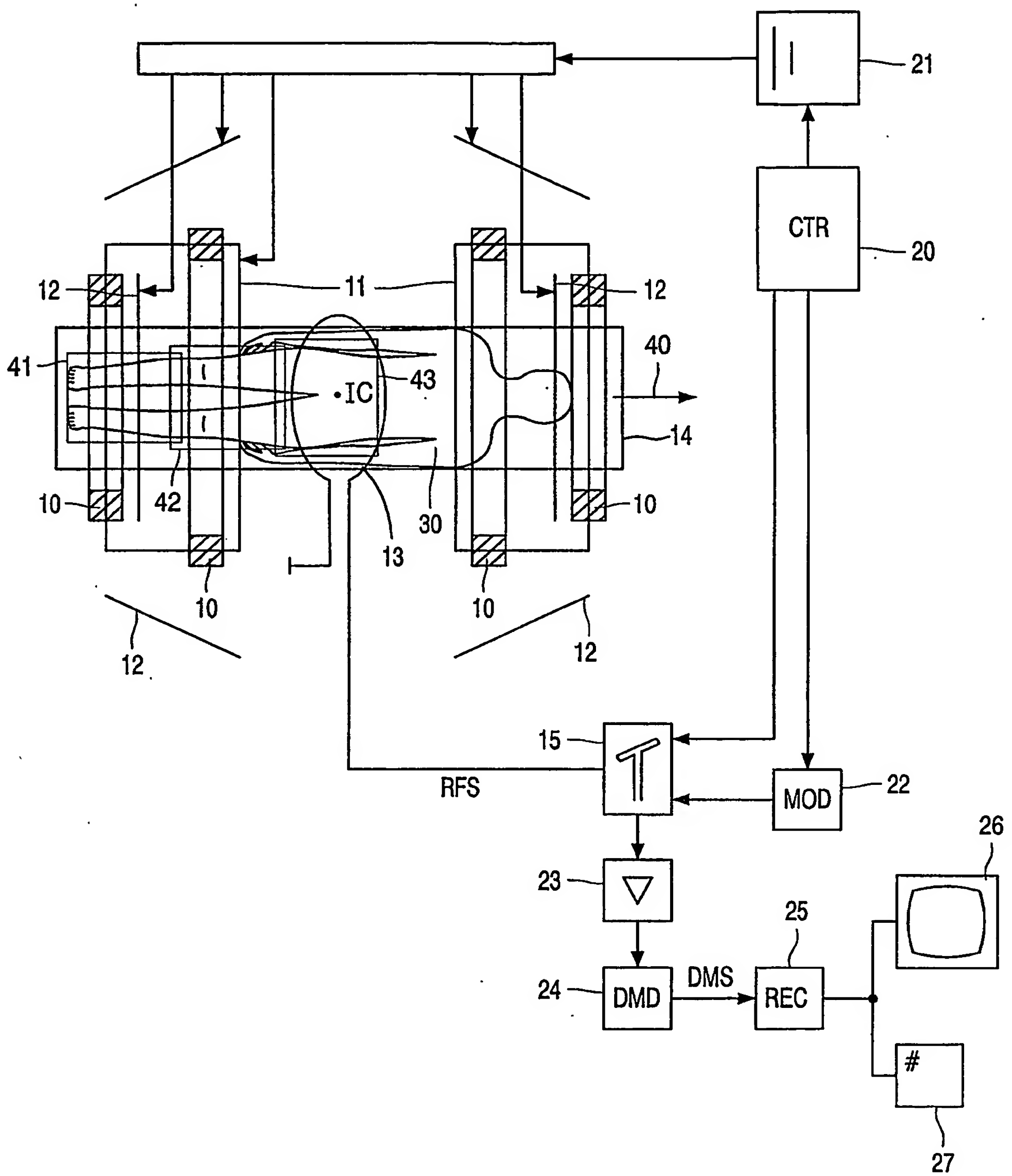
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FIG. 1

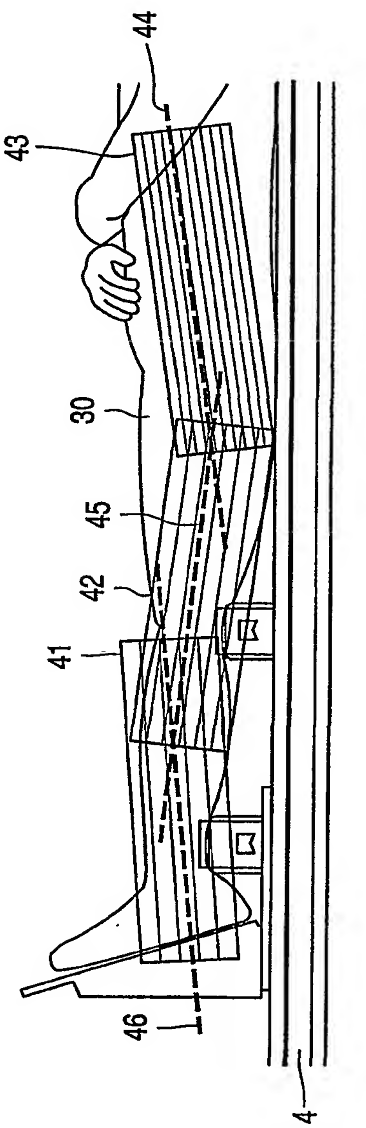

FIG. 2